

# AGN Feedback: Does it work?

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**Abstract.** While feedback is important in theoretical models, we do not really know if it works in reality. Feedback from jets appears to be sufficient to keep the cooling flows in clusters from cooling too much and it may be sufficient to regulate black hole growth in dominant cluster galaxies. Only about 10% of all quasars, however, have powerful radio jets, so jet-related feedback cannot be generic. The outflows could potentially be a more common form of AGN feedback, but measuring mass and energy outflow rates is a challenging task, the main unknown being the location and geometry of the absorbing medium. Using a novel technique, we made first such measurement in NGC 4051 using XMM data and found the mass and energy outflow rates to be 4 to 5 orders of magnitude *below* those required for efficient feedback. To test whether the outflow velocity in NGC 4051 is unusually low, we compared the ratio of outflow velocity to escape velocity in a sample of AGNs and found it to be generally less than one. It is thus possible that in most Seyferts the feedback is not sufficient and may not be necessary.

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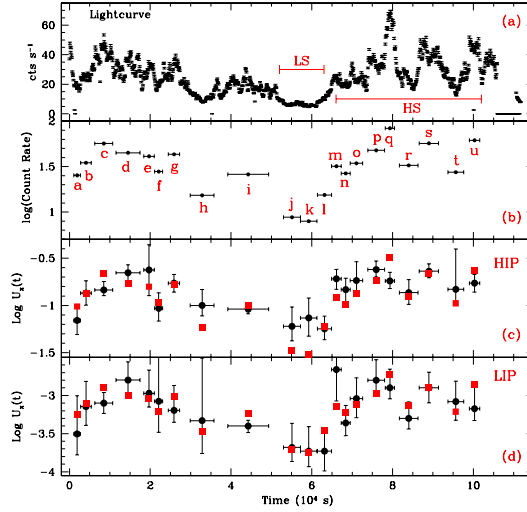
## AGN outflows

Feedback from AGNs has been invoked to solve a number of astrophysical problems, ranging from cluster cooling flows to the structure of galaxies. The outflows are ubiquitous in AGNs and could potentially provide a form of AGN feedback more common than jets; they may also be responsible for enriching the intergalactic medium with metals. Understanding the physical conditions in the absorbing outflows, particularly measuring their mass and energy outflow rates, thus becomes very important.

With the gratings available on *Chandra* and *XMM-Newton*, the past 10 years have seen a great progress in understanding the physical properties and kinematics of warm-absorber outflows<sup>1</sup>. A consistent picture has emerged from recent observations of several AGNs. The absorbers have at least two components: with a low ionization parameter (LIP) and a high ionization parameter (HIP). The LIP and HIP phases appear to be in pressure equilibrium, and so likely emerge from the common wind (e.g. Netzer et al. 2003). The LIP component is also responsible for the UV absorption lines (often show-

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<sup>1</sup> There have been several claims of relativistic outflows in the literature; we do not discuss them here. Vaughan & Uttley (2008) have argued that these are consistent with statistical fluctuations, given publication bias.



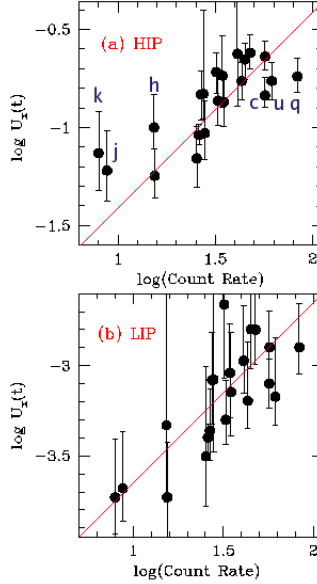
**FIGURE 1.** The XMM light-curves of NGC 4051. The continuum and the binned continuum are shown in the top two panels. The bottom two panels show variations in the ionization parameter of HIP and LIP. For comparison with the continuum level, the red squares represent the count rate with a constant offset. Note that the HIP is out-of-equilibrium at times h, j, k, q.

ing multiple components unresolved in X-ray), but the HIP is not. Several AGNs, especially those observed with the high energy transmission grating (HETG) on *Chandra*, show signs of an additional super-high ionization component (SHIP), also in pressure equilibrium with other components. In spite of these strides, there are still important unanswered questions: where do the outflows originate from; an accretion disk (e.g. as suggest by Proga, 2007) or the obscuring torus as suggested by Krolik & Kriss (1995)? This uncertainty of six orders of magnitude in radial distance is embarrassing. As noted above, an important question, particularly for the feedback process, is how much mass, energy and momentum do they carry.

## Feedback from outflows: a challenging measurement

In theory, energy injection efficiencies range from order of unity ( $L_{outflow}/L_{bolometric} \approx 1$ ) to a minimum of 5% (e.g. Silk, 2005 and Scannapieco & Oh, 2004). However, do we know whether actual quasar outflows can indeed carry such energy? This is a challenging measurement to make, the main unknown being the location and geometry of the absorbing medium. If the absorber geometry is, for example, a thin shell of gas located far from the nuclear black hole, then for a given column density the implied mass could be quite large compared to an absorber located closer in. The mass together with the outflow velocity (measured from the blueshifts of absorption lines) then allows us to calculate the energy outflow rate. Thus it is vital to know the location of the absorber.

However, in the equation for the photoionization parameter ( $U \propto L/n_e R^2$ ), the radius of the absorbing region ( $R$ ) is degenerate with the density ( $n_e$ ). This degeneracy can be



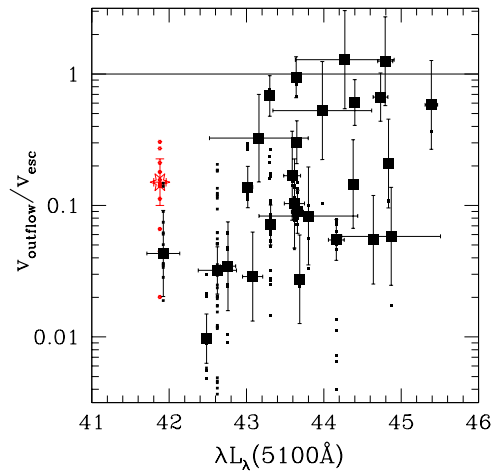
**FIGURE 2.** The ionization parameters of HIP (top) and LIP (bottom) are plotted as a function of the count rate. Both components follow the photoionization equilibrium, except for the points h, j, k, q of the HIP.

broken if we can determine the density independently. Since the recombination times are inversely proportional to density, the response of absorption lines to continuum variations during the ionizing phase provides a robust density diagnostic. Thus we must probe the appropriate time domain for an ionizing/recombining (rather than photoionization-equilibrium) plasma.

## The outflow rate in NGC 4051

In an XMM observation, a high resolution grating spectrum could be observed simultaneously with the low resolution CCD observation. For NGC 4051, the grating spectrum provided the accurate baseline model of the absorber while the time resolved spectroscopy could be performed with the CCD data. Because of the broad features in the spectrum, such as the Fe UTAs (unresolved transition arrays), the changes in the ionization state of the absorbers could be tracked even with the CCD data, knowing the base-line model (see figures 1, 2).

Using this novel technique, Krongold et al. (2007) managed to determine the absorber density in this system, so the distance. They determined the distance of the HIP from the nucleus to be 1 light day, and that of the LIP to be  $\leq 3.5$  light days. These results strongly argue in favor of an accretion disk origin for the winds. For the bi-conical outflow geometry expected from disks, the resulting mass outflow is  $\sim 10^{-4} M_{\odot} \text{ yr}^{-1}$  with an energy outflow rate of  $\sim 10^{38} \text{ erg s}^{-1}$ , 4 to 5 orders of magnitude *below* those required for efficient feedback.



**FIGURE 3.** The ratio of outflow velocity to the escape velocity appears to be less than one in most AGNs. The red diamond point is for NGC 4051.

## Scaling the outflows in other AGNs

How generic is the NGC 4051 result? NGC 4051 may be an unusual object, given that it is a narrow-line Seyfert 1, has low luminosity, and a low mass black hole. In NGC 4051, the outflow velocity is a small fraction of the escape velocity at the wind launching radius. Perhaps we are observing the wind before it is fully accelerated in this AGN because of the presence of a transverse flow in our line of sight. In other AGNs, perhaps,  $v_{wind}$  is equal to  $v_{escape}$ . To test whether this is indeed the case, we compared  $v_{wind}$  to  $v_{escape}$  for a sample of AGNs. Here  $v_{wind}$  is the outflow velocity as observed in UV absorption lines and  $v_{escape}$  was calculated scaling the wind radius from the NGC 4051 value (see Stoll et al. 2009 for details).

As shown in figure 3, for most AGNs  $v_{wind}/v_{escape} \ll 1$ . The result remains the same if we scale the wind radius with  $L^{0.5}$  or with black hole mass. Thus NGC 4051 does not appear to be unusual in its outflow velocity. It is thus highly likely that mass and energy outflow rate in most Seyfert galaxies is much too small to account for the kind of feedback required by theoretical models (see Stoll et al. 2009 for possible caveats).

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